NASA Green Aviation Workshop
April 25-26, 2009

# Greening Propulsion and Power from Today to 2030+"

- Reduce noise with improved efficiency
- Zero carbon
- No emissions

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# SFW N+2 Efficient Low Noise Hybrid Wing Body Focused on Low Noise



## Phase I Based on Goals in 2007 for 2020 Service Entry

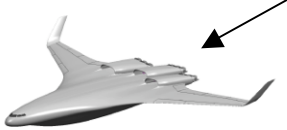
2025 Technology SAX 40
Non-Proprietary Aero Lines
Proprietary Propulsion

| | "N+2" Generation Hybrid Wing 2018-2020 |
|---|---|
| Noise (cum below Stage 3) | - 52 dB |
| Performance: Aircraft Fuel Burn (relative to current technology | - 25% |

Improved Noise Prediction Methods

Engines Moved Forward and added verticals for Aft Propulsion Noise Shielding

ICAO Annex Code E
Refine aero
Improve Structural Integration
NASA GRC Propulsion
Conventional Design Practices
2020 Service Entry



N2B Embedded GRANTA Type
Non-Proprietary Aero Lines
Non-Proprietary Propulsion
Reduced Risk 2020+ Technology

N2A Podded Engines for Low Risk 2020 Technology

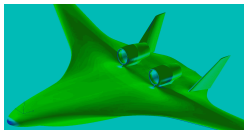
| N2A Status Efficient Low Noise Hybrid Wing Body 2020 |
|---|
| - 46.7 dB |
| - 29% |

## Phase 2

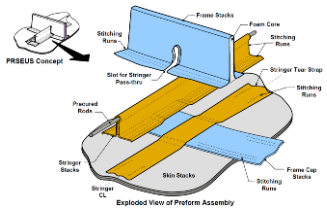
Continue N2A and N2B improvements
Continue Noise Prediction Improvements
Wind Tunnel Model for NASA test GFY 2011
**Enable low noise for 2020**

# INVESTIGATIONS FURTHER REDUCING HWB FUEL BURN

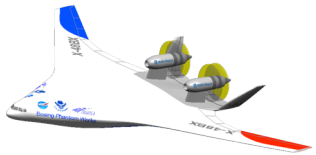




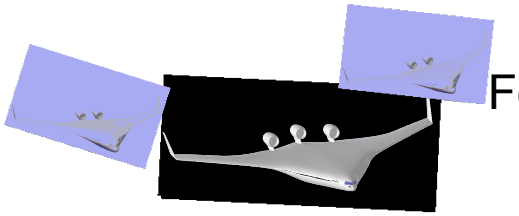
Efficient propulsion/airframe integration (with low noise)



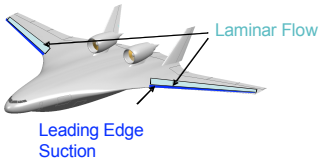

Damage Arresting Composites: Pultruded Rod Stitched Efficient Unitized Structure (PRSEUS)



Highly efficient propulsion cycles (open rotor)



Formation flying (BWB can vary span loading)

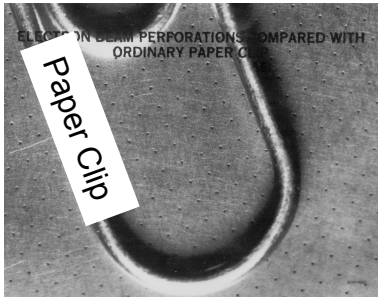



Hybrid Laminar Flow Control

# Flight Tests Are Needed



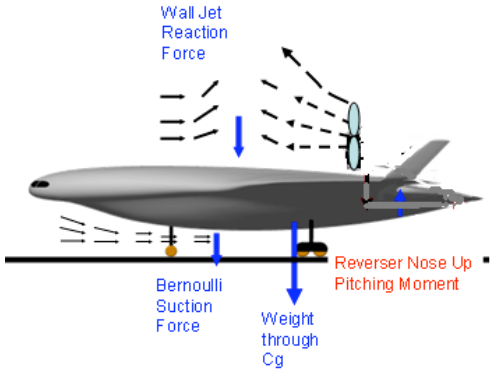
**Flying Qualities/Post Stall Recovery**




**HLFC uses porous surface with 0.0025 holes**

**Can not test scale model of large HLFC system in a wind tunnel**

**Dynamic Effects require flight testing**




**NASA Refan Flight Demo of low noise on DC-9 led to MD-80**

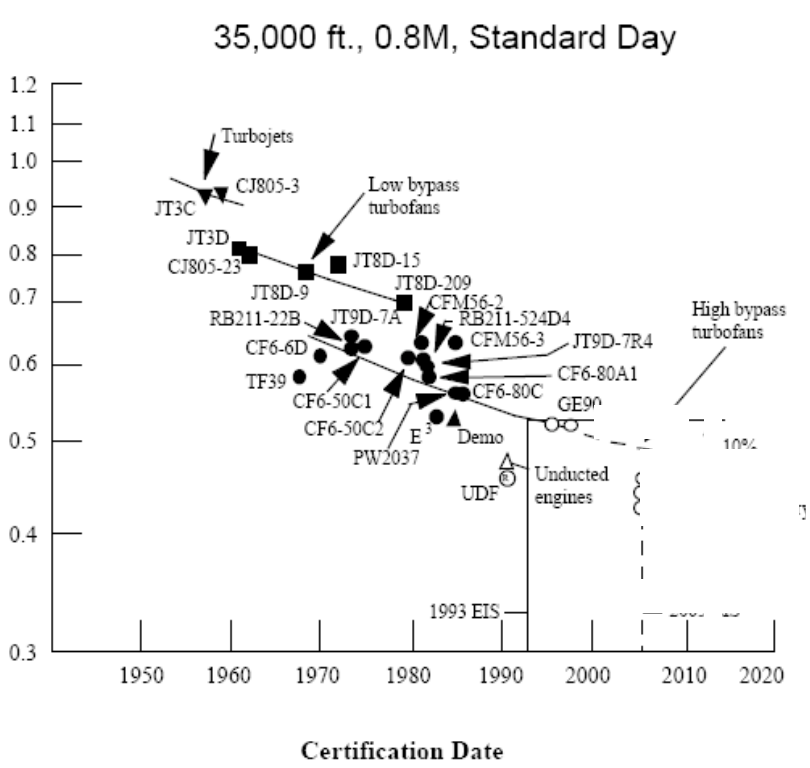
# Flight Validation for Opportunities Beyond 2020



- Flyover noise
  - EPNdB for very low noise
- Propulsion dynamic operability
  - Boundary layer ingestion inlets
  - Open rotor in real environment
- Post stall recovery
  - Ultra high by-pass ratio engines on HWB
- Laminar flow control
  - Hybrid full scale validation
- PRSEUS manufacturing scale up
  - Validate on full scale structures

# Alternate Energy for 2030 to 2050









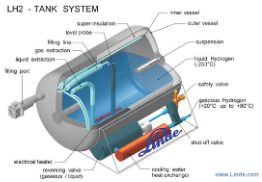
Hydrogen is zero carbon
Nuclear Power has no emissions

# Hydrogen Infra-Structure is Evolving

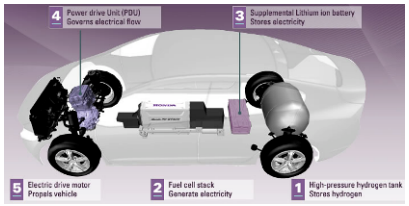



Hydrogen Buses in Europe and Canada


Jay Leno has Liquid Hydrogen/Gasoline BMW




**GM Equinox GH2 Fuel Cell**


**Honda Clarity GH2 Fuel Cell**

- H2 fuel cell powered buses are used in Europe
- Ford is developing a H2 turbocharged piston engine (used in Boeing HALE)
- BMW LH2 dual fuel developed
- GM and Honda GH2 Fuel Cell Cars Available in California
- Hydrogen stations located from San Diego to Burbank, California
- Honda Home Energy Station generates hydrogen from natural gas, with fuel cell cogeneration for heat and electricity and H2 for fuel cell vehicle.
- The future vision is production of hydrogen from nuclear or renewable source

# Self Fulfilling Prophecies



## Needs stimulates technologies to fulfill needs

Mutant Algae Is Hydrogen Factory: Anastasios Melis, Professor, UC Berkeley has engineered a strain of pond scum that could, with further refinements, produce vast amounts of hydrogen through photosynthesis.

The U.S. Energy & Environmental Research Center (EERC) Foundation has received U.S. patent approval for a system that produces high-pressure hydrogen on-demand. The new technology is the basis for a U.S.–Israel hydrogen fueling demonstration on the feasibility of using hydrogen as a fuel for buses in North Dakota and Tel Aviv, Israel.

Toshiba, Los Alamos, Hyperion, others reported to be developing 10-200 MW mini nuclear reactors to be safe by sealing and locating underground for cost competitive electric power: H2 from electrolysis of H2O or, sealed nuclear powered very large aircraft

Forbes April 13, 2009 “A fusion-fission hybrid reactor could produce clean electricity ... Livermore National Ignition Facility director Moses imagines .. demonstration plant 2020 and commercial technology by 2030”

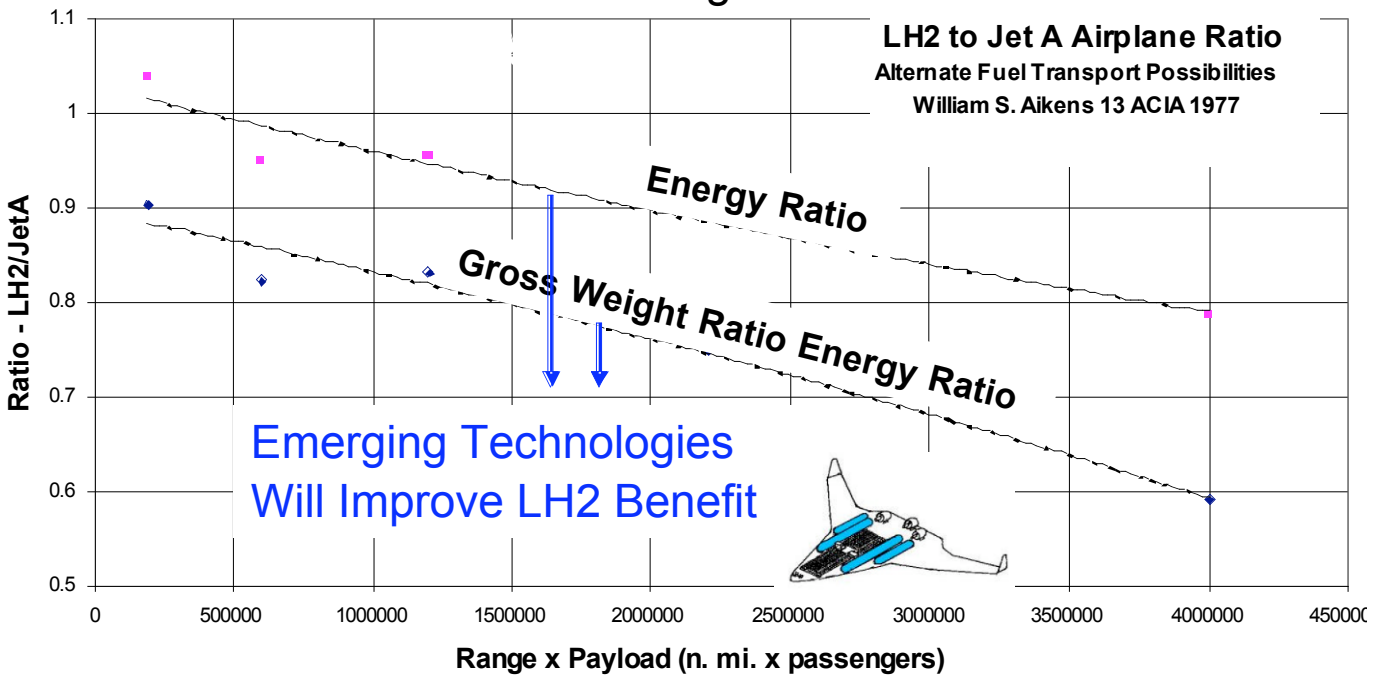
Continuation of Globalization and World Economic Growth with Energy Independence and Emissions Containment may require reassessment of alternatives

# LH2 Potential is for Large Long Range Aircraft



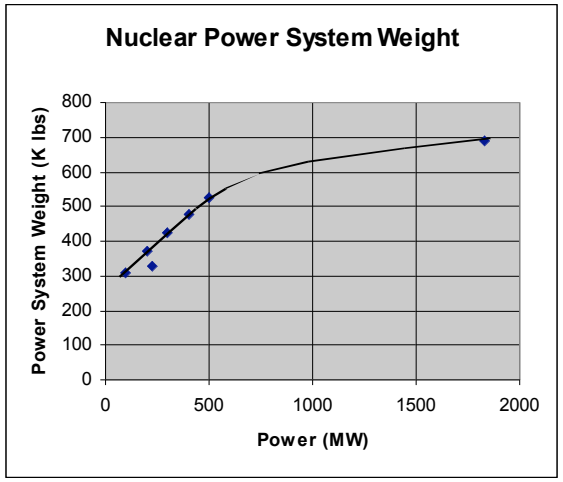
| | Jet A | LH2 | LH2/Jet A |
|---|---|---|---|
| **Combustion Heating Value (BTU/lb)** | **18,580** | **51,000** | **2.74** |
| **Liquid Density (lb/ft$^3$)** | **6.7** | **0.6** | **0.09** |
| **Energy Density (1000 BTU/ft$^3$)** | **124** | **30.6** | **0.25** |
| **Modern Engine SFC (lb/hr/lb)** | **0.53** | **0.19** | **0.36** ← **64% Better SFC** |
| **Max Liquid Storage Temperature (°F)** | **120** | **- 423** | |

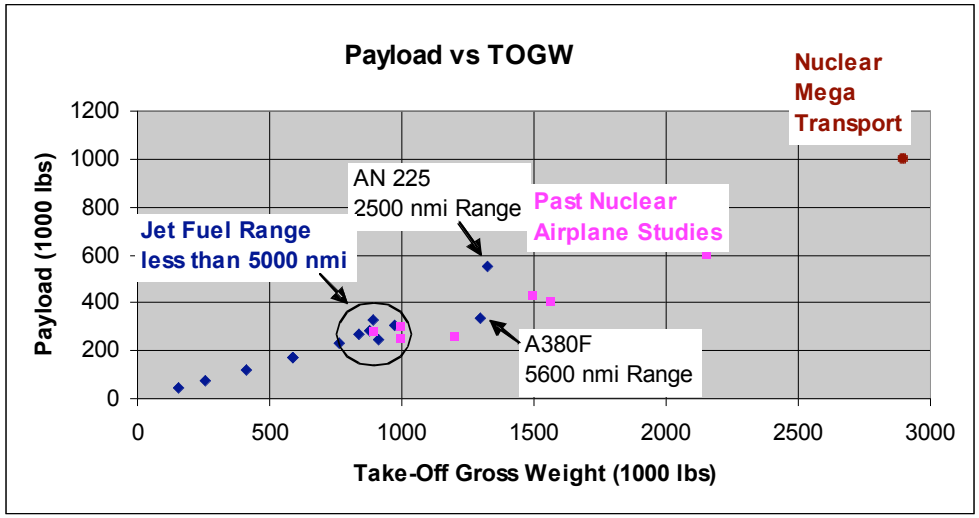
## SFC Benefit for Wing and Tube



# Nuclear Powered Potential is for Ultra Large Aircraft






| | | | | | | |
|---|---|---|---|---|---|---|
| SAE 79-0846 | AIAA | TM | AIAA | RAND | SAE | Boeing |
| Muehlbauer | 82-0804 | X-2386 | 67-508 | | 79-0852 | D162- |
| LG | Brewer | Rom | Wild | 1889/1-AF | Layton | 10175-1 |
| | | | | Mikolowski | | |

## OUT OF THE BOX VISION FOR 2040-2050

TOGW at 1M **+** lbs passes the weight threshold for nuclear power

D u a l f u e l c o n c e p t :

- Nuclear power to generate LH2 during ground sit
- TO and Landing on LH2 with liquid metal HTX reactor closed off
- LH2 Fuel Cell APU for secondary power while providing cooling for superconducting electric power systems